



U.S. Department of Energy Hydrogen R&D Program

**NASA Environmental Compatibility Research Workshop III
Monterey, California**

**Neil Rossmeissl, Hydrogen R&D Program Manager,
U.S. Department of Energy**

**Jim Ohi, Center for Transportation Technologies and Systems
National Renewable Energy Laboratory**

July 7, 1998



Program Mission

The DOE Hydrogen Program conducts applied R&D in hydrogen production, storage, and utilization to enable hydrogen to be a cost-effective energy carrier for utility, buildings, and transportation applications. The Program will accomplish its mission by:

- Funding projects that decrease the cost of producing hydrogen from natural gas and that introduce renewable-based options to produce hydrogen
- Developing hydrogen-based electricity storage and generation systems that will enhance distributed renewable-based utility systems
- Demonstrating safe and effective fueling systems for hydrogen vehicles in urban non-attainment areas
- Developing and lowering the cost of technologies to produce hydrogen directly from sunlight and water



Recent Trends

-
- **Significant political interest in global climate change**
- **Significant industry investment in PEM fuel cell technology**
 - Ballard/Daimler Benz (20 beta units by 2000)
 - Plug Power [MTI/Detroit Edison] (residential units by 2000)
 - IFC (successful 50 kW automotive prototype)
 - EPI (promoting electric applications with utility)
- **Significant industry investment in hydrogen production from natural gas**
 - IFC/Praxair (steam reforming/PSA)
 - Air Products and Chemicals (SER & ITM)

PEMFC Multisector Activities

Office of Transportation Technologies

Light & Heavy Vehicle Power Systems

- On-board Fuel flexible reforming
- PEM Stack Engineering
- Vehicle System Integration/Demos

H2 Vehicle Demos
H2 Storage Tanks

OUT

H2 Refueling Station
Electrolysis
Reversible Fuel Cells
H2 Storage (chemical)
Distributed Utility
PEMFC
Portable PEMFC

MEAs
Bipolar Plates
Controls

CO Clean-up
PEMFC/NG
Reforming

Stationary Demos

Stationary/commercial Power Systems
Stationary Stack Engineering/design
Cogeneration

Office of Utility Technologies

Office of Building Technologies

DOE Hydrogen Related R&D

Office of Fossil Energy

- Coal gasification
- Sequestration
- Fuel Cells
- High-value Carbon Products

OUT

Storage

- Metal hydrides
- Carbon materials

Production

- Electrolysis

PEM Fuel Cells

- Stationary
- Portable

- C- Storage Materials
- Reforming
- Composite Tanks

- Photobiology
- Materials & Catalyst R&D

- Photobiology
- Materials
- Catalyst
- Reactive flows

- Photosynthesis
- C-Nanostructures
- H₂ Corrosion

Office of Energy Efficiency & Renewable Energy

Office of Energy Research



Program Activities Summary

Hydrogen Production \$3.8MM US

Long-Term Goals	Short-Term Goals	Primary Performers
Demonstrate advanced natural gas-based hydrogen production technologies with higher efficiencies and lower capital cost than conventional steam methane reforming.	Build 500 scf/day sorbent-enhanced reforming testing unit (98) Design POX PDU based on ITM technology (01)	Air Products and Chemicals
Develop biomass/MSW-based hydrogen production processes	Design pyrolysis PDU and begin construction (98) Demonstrate supercritical gasifier operation (00)	NREL University of Hawaii
Continued research and development of photoelectrochemical (PEC) and photobiological hydrogen production processes	Build prototype monolithic PEC system (99) Demonstrate <10 ppm CO in effluent of WGS reactor in continuous operation (98)	NREL, Hawaii NREL



Program Activities Summary

Hydrogen Storage \$1.67 MM US

Long-Term Goals	Short-Term Goals	Primary Performers
Develop low-cost and low-weight hydrogen storage technologies, addressing both stationary and transportation-based applications, as well as transport of hydrogen	Build prototype Mg hydride storage tank with H ₂ storage density of 3 wt% and dehydrating T < 200C (98)	SNL ECD
	Demonstrate 2 wt% in room-temperature carbon nanotube system (98)	NREL
	Explore potential of novel storage concepts (99) fullerene, nanowhiskers, phase change hydride, polyhydride, chemical hydride	ORNL Northeastern U Arthur D. Little U of Hawaii Tecogen



Program Activities Summary

Hydrogen Utilization \$0.8MM US

Long-Term Goals	Short-Term Goals	Primary Performers
Develop low-cost reversible fuel cell	Design 5 kW system (98)	LLNL, LANL
Enable development of more reliable, less expensive sensors	Fabricate and deploy fiber optic sensors (98)	NREL



Program Activities Summary

Technology Validation \$2.8MM US

Long-Term Goals

Validate sustainable hydrogen systems for utility and vehicular applications

Short-Term Goals

- Foster business opportunities for industry in H₂ energy applications through 1-2 phase II cost-shared awards
- Identify opportunities for renewable H₂ systems in utility applications through phase I awards (98)
- Build hydrogen gas vehicle fueling station
- Convert mall utility vehicle to PEM fuel cell power system
- Complete validation exercise for vehicles fueled by and of hydrogen and natural gas

Primary Performers

TBD

TBD

Humboldt State University

NRG



Program Activities Summary

Technology Validation \$2.8MM US

-- Continued --

Long-Term Goals

Validate sustainable hydrogen systems for utility and vehicular applications

Short-Term Goals

Develop interest in owning and operating hydrogen-fueled vehicles; establish fueling infrastructure as needed

Demonstrate operation of carbon-wrapped pressure vessel in gaseous H₂ service at 5 kpsi (98)

Prove cryogenic pressure vessel concept by testing carbon wrapped vessel in LH₂ service (98)

Primary Performers

SNL, LLNL

Tecogen, Thiokol

LLNL, SCI



Program Activities Summary

Systems Analysis \$2.3MM US

Long-Term Goals	Short-Term Goals	Primary Performers
Evaluate and analyze technologies and processes to identify pathways that will enable hydrogen implementation	Utility applications, distributed generation and H2 co-product (98)	DUA, LLNL
	Vehicle applications and infrastructure opportunities in NE (98)	DTI, Princeton U
	Assess market conditions (98)	NHA, SEIA
	Conduct process analyses (98)	NREL
	Conduct technology characterizations (98)	Energetics
	Support IEA and HTAP (98)	NREL, Energetics
	Provide outreach and education (98)	Sentech



Activities Related to Presidential Initiatives

- **Global Climate Change**



- Biomass gasification and advanced reforming technologies minimize CO₂ emissions and are amenable to CO₂ capture and sequestration



- Hydrogen Program systems analysts supported recent discussion on greenhouse gas emissions reduction strategies





International Collaborations

-
- **Joint venture with Japan and Italy**
 - demonstrate photobiological production at University of Hawaii
- **International Energy Agency**
 - develop 5 new annexes with other member countries
 - establish visiting scientist program with national laboratories and universities

—



1997 Accomplishments (selected)

- Sandia National Laboratory developed Mg/Zn/Al alloys with properties attractive for vehicle applications (i.e., dehydriding temperature $<200^{\circ}\text{C}$, 3 wt%)
- NREL patented fiber optic sensor design with greatly improved response time and vibration tolerance
- Analysis of cryogenic pressure vessel concept by Lawrence Livermore National Laboratory showed enough promise to merit a validation exercise in FY98
- Published solicitation for integrated renewable/hydrogen utility systems



R&D Highlight - Production

Sorption Enhanced Reforming

Develop a low-temperature SMR process with a hydrogen production cost 25% lower than conventional SMR

- Air Products and Chemicals, Inc., developed materials that selectively adsorb CO₂ in a hydrothermal environment
- Analysis of a SER process using these materials indicates favorable hydrogen production cost
- APC will build experimental unit (500 scf/day) in 1998 to test full cyclic reaction/regeneration process



R&D Highlight - Storage Magnesium-based Hydrides

Develop a hydride material that stores hydrogen at 4 wt% and releases it at 150°C and 1 atmosphere.

- SNL found promising results with Mg/Zn/Al alloys
 - 3 wt% @ 200 C
- Developed and tested prototype hydride vessel
 - met all design specifications
 - demonstrated fill time of 6 minutes
- Will integrate Mg-based alloy into hydride bed system in 1998



R&D Highlight - Utilization Fiber Optic Hydrogen Sensor

Develop a reliable, low-cost, hydrogen-specific sensor for automobile and industrial applications

- NREL invented and patented FO sensor design that greatly improves response time and vibration tolerance
- Initiated CRADA with a small business partnership to commercialize the technology
- NREL and its CRADA partner will fabricate prototype sensors and field test them in 1998



Selected Planned 1998 Accomplishments

- Demonstrate continuous operation of SER PDU
-
- Demonstrate reforming of pyrolysis oil
-
- Demonstrate Mg-based hydrogen storage system with a dehydrating temperature of 200C and system hydrogen storage density of 3 wt%
-
- Complete design of carbon-wrapped pressure vessels in hydrogen service, both gaseous and liquid
-
- Demonstrate field operation of fiber optic hydrogen sensors



Hydrogen for Subsonic Flight

- **Prepare scenario(s)**
 - Hub to hub (e.g., Dallas/Ft Worth-Washington, DC)
 - East coast/west coast hub to Europe/Asia hub
- **Conduct systems analysis**
 - Technical requirements(aircraft, support, servicing, etc)
 - Review NASP reports
 - Safety, regulatory, certification
- **Develop Action Plan**
 - National Hydrogen Aircraft Consortium
 - Appoint Integration Management Contractor
- **Conduct NASA-DOE joint venture**
 - NASA retrofits airplane
 - DOE provides fueling infrastructure
 - Acquire performance and emission data



Starting Point for Proposed Scenario

-
- **Small aircraft demonstration**
 - LA (Ontario-Praxair) to San Francisco (Air Products)
 - Federal Express delivery route
- **Dallas-Ft. Worth to Washington, DC, National**
 - Fewer than 10 flights/day
 - Liquid H₂ (12,000 gal semi-trailer) delivered to airport
 - 33,000 gal storage tank on-site
 - Shuttle trucks (4-5,000 gal), one truck per plane
 - Hydrogen provider owns equipment
 - More than 10 flights/day
 - SMR plant built at each airport
-
-